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2. Patent application number *(The Patent Office will fill in this part)* — 0322681.8

3. Full name, address and postcode of the or of each applicant (*underline all surnames*) — KONINKLIJKE PHILIPS ELECTRONICS N.V.
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   Patents ADP Number (*if you know it*) — 07419294001

   If the applicant is a corporate body, give the country/state of its incorporation — THE NETHERLANDS

4. Title of the invention — MULTI-VIEW DISPLAY

5. Name of your agent (*if you have one*)

   "Address for service" in the United Kingdom to which all correspondence should be sent (*including the postcode*) — Philips Intellectual Property & Standards
Cross Oak Lane
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Surrey RH1 5HA

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DESCRIPTION

MULTI-VIEW DISPLAY

The present invention relates to display devices and, in particular (but not exclusively) to multi-view , or dual-view , displays.

One use for such devices is in automotive applications with the display in the dashboard area such as to allow the driver and one or more of the passengers to look at different information presented on the same display, see Figure 1. For instance, the driver views the route-planner, while the passenger reads his e-mail or views a DVD.

For safety reasons the driver is not allowed to see the information presented to the passenger. So, the regions in which the driver and passenger can see their information should fulfill specific requirements. In a typical automotive application the viewing zone intended for the driver and passenger should fulfill the requirements denoted in Figure 2.

In most embodiments known so far, in between the viewing zone intended for the driver and passenger there is a zone in which the information that is intended for both viewers is visible at the same time. In this region there is cross-talk. For an automotive application this is undesirable, since a passenger sitting in the middle of the rear bank will sit precisely in this cross-talk region and perceive confusing information.

In the following we review known embodiments, such as those presented in the applicants earlier European patent application 02078417.9 filed 19th August 2002 (PHNL020770), which cannot fulfill the requirements for an automotive application as the viewing zones are very small and there is a large region with cross-talk. Subsequently, we describe our solution based on a dedicated back-light combined with a lenticular screen. In a first embodiment there is no cross-talk and the viewing zones are larger than in prior art embodiments such as those described in European patent application 02078417.9.

1 Problem description

Several embodiments of multi-view displays are described in applicants earlier case European patent application 02078417.9, and will be briefly reviewed here. A first embodiment is based on a lenticular screen placed in front of a LCD (liquid crystal display), see Figure 3. This construction is also used to create a multi-view 3D display in which the information of different sub-pixels is aimed at the left and right eye such that an auto-stereoscopic picture is created. The drawback of this construction is that it is not possible with presently available LCD screens that have a glass thickness of 0.7 or 1.1mm to create large viewing angles. In addition, there is a large region in which there is cross-talk only.

One can use a front barrier to create two or more views, see Figure 4: this principle is also used to create auto-stereoscopic displays. Again this embodiments suffers from the small viewing zones and a large amount of cross-talk. In addition, this arrangement is not very light efficient since a large amount of light is blocked by the barrier.

Figure 5 shows the different viewing zones for a front barrier with a pixel size of 300μm, a black matrix width of 25μm and a glass thickness of 700μm as a function of the transmission, i.e. width of the slit, of the barrier. It will be observed that there are small regions in which there is no cross-talk and large regions in which there is cross-talk. The largest obtainable viewing zones correspond to a transmission of the front barrier of zero and are nearly 40 degrees large. If the transmission is 25% the viewings have reduced to approximately 10 degrees and the cross-talk in between the views ranges from minus 10 degrees to plus 10 degrees.

In conclusion, the presently known embodiments of a multi-view display suffer from viewing zones that are too small and from large areas in which there is cross-talk. Without additional measures it is not possible to create viewing zones that are sufficiently large.

2 Proposed solution

Before explaining our preferred embodiment, for the purposes of illustration we first introduce an embodiment that has, compared to the prior art embodiments discussed, relatively large viewing zones, but still has regions with cross-talk. A sketch of this embodiment is shown in Figure 6. For simplicity we assume that we deal with a back-light that acts as a collimated light source. Alternatively we might use a back-light that emits light along lines. Between the back-light and the LCD display there is a lenticular screen. Due to this screen light lines are created in the glass of the LCD. The opening angle of this light line and the width determine the size of the viewing zones and the zones with cross-talk respectively. The maximum viewing angle is determined by the thickness of the LCD glass and the width of the LCD (sub-)pixels.

If we assume that the glass thickness is 0:7mm and that the pixels are oriented as denoted in Figure 7, the maximum usable viewing angle is 72 degrees. If the width of the light line is 100μm, the zone with cross-talk is 24 degrees.

The embodiment we propose works by using a back-light that emits light along light lines. The pitch of the light lines is (aside from a correction discussed below) equal to two times the (sub-)pixel pitch. Between the back-light and the LCD screen there is a lenticular. This lenticular has the same pitch as the back-light and the lenses are positioned in between the light-lines as denoted in Figure 8. The strength of the lenses is chosen such that the light-lines are imaged into the (sub-)pixels. In reality the size of this image should be less than the (sub-)pixel size.

It may be shown that, assuming a pixel orientation as denoted in Figure 7 and a glass thickness of 0:7mm, the viewing zones have an angular size of 30 degrees. The region in between the viewing zones is 12 degrees and there is no cross-talk. The light rays for this calculation are shown in Figure 9.

In Figure 8 the light line is imaged in a pixel that is just on the left or right of the lens that performs the imaging. Other constructions are possible in which pixels that are further away from the lens are used. In such a

construction the size of the region in which no information is visible will be increased.

For screens that have a large size compared to the distance between the viewer and the screen a view point correction is needed. If the pitch of the lenticular and the light-lines is precisely two times the (sub-)pixel pitch, the viewer might not be able to observe the whole screen at one position. This is illustrated in Figure 10. Applying a view point correction, whereby the pitch of the lenticular and the light-lines is slightly larger than two times the (sub-)pixel pitch, the viewer is able to observe the whole screen. In practice the view point correction is used to optimize the size of the viewing zones.

The size of the viewing zones can be improved by means of a dedicated scatterer. For a dual-view display there is a viewing cone between the first and second viewing zone in which no information is visible. By means of a dedicated scatterer the first and second viewing zones can be enlarged and the zone in which no information is visible can be filled with useful information. This is illustrated in Figure 11.

The scatterer should fulfill special requirements. To avoid cross-talk between the views the scattering profile should not have any shoulders, as denoted in Figure 12. Such a scatterer may consist of a rough surface with controlled surfaces, as denoted in Figure 13. The controlled diffraction on the surface will result in the preferred scatter profile. The width of this profile should be less than the zone between the first and second viewing zone. Alternatively the scattering surface might be structured as denoted in Figure 14. The surface is not necessarily sphere like. The structures should be small compared to the sub-pixel distance, for example 10 to 50μm.

We now propose a method to allow switching between a dual-view mode and a single view mode. In the dual-view mode only half of the (sub-) pixel is visible by each viewer, while in the single view mode all pixels are visible by both viewers. By placing a diffuser between the lenticular and the LCD screen, the LCD screen is lit uniformly, see Figure 15. For the diffuser a switchable material like PDLC or LC-gel might be used.

The foregoing describes a multi-view display that has large viewing zones and does not have zones in which both views are visible at the same time. This multi-view display consists of a back-light that emits light along lines and a lenticular screen. This lenticular screen is such that the light lines are imaged into the (sub-)pixels. The light lines are positioned in between the lenses of the lenticular screen.

Compared to known embodiments, the above-proposed embodiment does not suffer from regions in which both views are visible. There is no cross-talk. In addition, the viewing zones are larger (30 degrees compared to 10 degrees) than the viewing zones realized with the prior art embodiments.

The viewing zones can be increased by means of a dedicated scatterer, which scatterer might consist of a rough surface where the facets make controlled angles. In a preferred embodiment, the above-described multi-view display can be made switchable between a dual-view mode and a single view mode by means of a switchable diffuser. Such a diffuser is placed between the lenticular and the LCD screen.

As will be recognised, where we have referred herein and hereafter to an LCD screen, any other display based on light shutters may be used.

Considering now a specific dual view implementation, in the known art, the odd and even columns of sub-pixels are directed to the first and second viewer respectively. In the following discussion the applicants disclose an arrangement using several adjacent sub-pixels for the first and second viewer. Below, based on this sub-pixel layout, two dual-view display embodiments are presented. The first embodiment is based on a rear barrier and a thin glass substrate. The second embodiment uses a LCD display with a normal glass thickness and is based on a back-light with light lines and some optics to image the light lines close to the sub-pixels.

A dual-view display is often thought to be a variant of a two-view three-dimensional display. Such a two-view three dimensional display can, for instance, be created by means of a rear barrier. This is illustrated in Figure 16. There are two views, one intended for the left eye and one for the right eye.

This construction can be applied for a dual-view display, as shown in Figure 17, however, the glass thickness should be small and there will always be cross-talk. To create two views that are well separated at ±30 degrees, as described earlier, the glass thickness should be less than p/0:3536 where p is the sub-pixel size [the light rays that go through the middle of the sub-pixels should go in a direction of ±30 degrees. Within the glass these angles should be ±19 degrees, so tan(19 degrees) = $1/2p/(1/2d)$ = p/d and d = p/tan(19 degrees)]. For a typical sub-pixel size of 99μm this results in a glass thickness of 280μm which is unrealistically small.

In addition to this thin glass, there is cross-talk between the two views. The slit has a finite width and therefore the two views overlap, as illustrated in Figure 17. Using a small slit reduces the cross-talk at the cost of a low transmission.

In all known prior art embodiments of dual-view displays, the cross-talk and the small viewing zones arise because the sub-pixels are small compared to the glass-thickness. In all these embodiments the odd and even sub-pixels are used for the first and second viewer respectively. The present applicants propose to use several adjacent sub-pixels for the first and second viewer, as illustrated in Figure 18. To avoid the cross-talk in between the views, the applicants use, a (or several) black sub-pixel(s) in between the sub-pixels for the left and right viewer. The number of adjacent sub-pixels to be used for each viewer is free.

The penalty of this black sub-pixel (or pixels) is a resolution loss. Assuming only one sub-pixel for each viewer in every period and one black sub-pixel, the period of this sub-pixel structure is 4 and in this case we use only 1/4 of the total number of sub-pixels for each viewer. If we use two sub-pixels for each viewer and one black sub-pixel, the period of the sub-pixel structure is 6. In this case we use 1/3 of the total number of sub-pixels for each viewer.

Hereafter applicants discuss, as an illustration, two dual-view displays that use a sub-pixel-layout as presented above. In this section there is

described a first dual-view display based on a LCD with thin glass substrate and a rear barrier that uses the sub-pixel layout as discussed above.

To explain our idea we start with a system in which we use periodically 6 sub-pixels in the horizontal direction. The first two sub-pixels are aimed at the first viewer, the third sub-pixel is intentionally left black to avoid cross-talk. The fourth and fifth sub-pixels are aimed at the second viewer and the last sub-pixel is again left black. This embodiment is illustrated in Figure 19: in this and subsequent Figures the refraction at the glass air interface is omitted for simplicity.

The thickness of the glass and the number of views behind every slit determine the size and direction of the viewing zones for both viewers. For instance, to obtain a viewing zone that is aimed at ±30 degrees, we can use glass that has a thickness of 1:5*p*=tan(19 degrees), where *p* is the sub-pixel size. (A direction of 30 degrees outside the glass means 19 degrees inside the LCD glass). For a typical sub-pixel size of 0:099mm this results in a glass thickness of 430μm (taking the refraction on glass-air interfaces into account).

The width of the slit determines the size of the viewing zone in which all the sub-pixels are visible. This is illustrated in Figure 20. For instance, for viewer 1, there is a region in which sub-pixel 1 is visible or sub-pixel 2 only. In between those two regions there is a region in which both sub-pixels are visible. It is this region that is of interest.

The cross-talk depends on the width of the slit. If the width of the slit is less than one sub-pixel, there will be no cross-talk. This is illustrated in Figure 21.

To calculate the size of the viewing zone, let us suppose that the width of the slit is equal to one sub-pixel. In the glass substrate the angle α_1 and α_2, see Figure 20, are given by:

$$\alpha_1 = \arctan(p/d) \quad \alpha_2 = \arctan(2p/d) \qquad (1)$$

As a function of p/d, the angles at which the viewing zone in which both sub-pixels are visible begins, α_1, and ends, α_2, are shown in Figure 22. For a display in which p = 0:099mm and d = 0:7mm we obtain p/d = 0:14 and the viewing zone starts and ends at 12 degrees and 24 degrees respectively.

A few measures can be taken to increase the viewing zone. Firstly, a diffuser may be put on top of the LCD to increase the angular spread of the views. For instance, a diffuser with an angular spread of 10 degrees. This will result in some cross-talk in-between the two-views and a loss of resolution in the vertical direction. In addition, the daylight contrast of the display will be reduced by the diffuser. An advantage of this solution is that in the horizontal direction the sub-pixelation due to the use of only 1/3 of the sub-pixels will be less visible.

Secondly, a diffuser that scatters in the horizontal direction only may be used. This has the same disadvantages and advantages as a normal diffuser, but does not suffer from the resolution loss in the vertical direction.

Thirdly, we might use a foil that scatters light in specific directions only, like the Lumisty foil (www.madico.com). Such a foil is transparent for light that enters the foil with an angle between ±15 degrees with respect to the normal of the surface and scatters light if the angle is larger. With such a foil we generate less cross-talk and the day-light contrast is less compromised.

Whilst the above uses six sub-pixels in every period, as explained, there are other periodic sub-pixel layouts possible as well. For every periodic structure we need 2 sub-pixels to avoid cross-talk between the two views. In addition, due to symmetry of the system, both viewers observe the same number of sub-pixels. This implies that the number of sub-pixels is an even number. For four and eight sub-pixels the embodiment is shown in Figure 23. For four sub-pixels all sub-pixels intended for a viewer are visible at the same time. For eight sub-pixels we have again two regions in which the first and third sub-pixels are visible only. In between there is a region in which all three sub-pixels are visible at the same time.

A drawback of a 4 sub-pixel embodiment is that we use only one out of four sub-pixels for each view. In a 6 sub-pixel embodiment we use 1/3 and in an 8 sub-pixel embodiment 3/8 of the sub-pixels. A drawback of 8 sub-pixels (or more) is that the distance between the sub-pixels intended for one viewer becomes larger which results in visual artefacts. Finally, a drawback of 6 sub-pixels is that this structure interferes with the colour filter lay-out such that the

viewers cannot see one of the three primary colors. This can be solved by means of another colour filter lay-out or by having a slant angle, for instance 1/3, between the slits and the colour filters (which might result in some cross-talk).

Suitably all pictures are drawn such that the light source has an angular spread which fits within the sub-pixels used in one period. In practice the angular spread is allowed to be larger at the cost of a repetition of the viewing zones at the left and right of the two zones in which we are interested, see Figure 24.

In the previous section we discussed a display of which the viewing angles for an off-the-shelf display were relatively small. This could be improved by thinner glass, or alternatively by means of a light line that is closer to the LC cells. It is the latter that we will perform in this section by means of a rear lenticular.

In this section we describe an embodiment that is based on a stack of a back-light that emits light along light lines, and a lenticular screen, see Figure 25. The lenses of the lenticular screen should have a pitch that equals six times the sub-pixel pitch (or 4, or 8 etc, depending on the number of sub-pixels used in every period).

Ideally, the design of the system should be such that there are light lines beneath the dark sub-pixel. The size of these light lines should be less than or equal to the dark sub-pixel to avoid cross-talk (as was illustrated in Figure 21 for the rear barrier solution). Since the pitch of the lenses is equal to six sub-pixels, the light line is at most at 5/11 of the glass thickness from the cells, see Figure 26. So, the ratio *p/d* reduces from 0.099/0.7 to 5/11*0.099/0.7 = 0.064. This implies that the viewing zone in which both sub-pixels are visible starts at α_1 = 26 degrees and ends at α_2 = 52 degrees.

In the above described embodiment the angular spread of the light lines is such that light rays emanating from a light line only arrive in the lens above the light line. This implies for a thin system, that the opening angle of the light lines should be small. In practice the opening angle is larger than a single lens.

For this larger opening angle, light is going through neighboring lenses and creating new unwanted light lines.

To deal with the larger angular spread the distance between the back-light and the lenticular should be such that the optical system has a magnification factor of 1 (or any other integer number). This is illustrated in Figure 27. For this magnification factor, the light rays that go through a neighboring lens are imaged on the light lines above another lens.

In the foregoing we have proposed to use several adjacent sub-pixel columns for the first and second viewer in a dual-view display instead of the odd and even column for the first and second viewer respectively as is done in all dual-view display discussed in the past.

The use of several adjacent sub-pixels columns results in larger viewing zones. An additional advantage of this solution is that we have more freedom to create a dual-view display. Normally, the glass thickness over sub-pixel size is the limiting factor in a dual-view display. By using several adjacent sub-pixels for one viewer, we can get ride of this limitation.

In order to avoid cross-talk, it is favorable to use a black sub-pixel between the adjacent sub-pixels for the viewers. For instance, in a system with a period 6 for the sub-pixel structure, we use sub-pixel one and two for view 1, three is black, four and five are used for view 2, six is black, seven and eight are used for view 1 etc.

There is a whole family of sub-pixel layouts possible. A period 4 sub-pixel layout consists of a sub-pixel for the first viewer, a black sub-pixel, a sub-pixel for the second viewer and a black sub-pixel. A period 8 sub-pixel layout consists of three sub-pixels for the first viewer, a black sub-pixel, three sub-pixels for the second viewer and a black sub-pixel.

It is sometimes favorable to slant the sub-pixel structure slightly. For instance, for the period 6 sub-pixel layout there is an interference with the colour filter such that both viewers see two out of three colours only. If we slant this sub-pixel layout over an angle of 1/3, all colours are visible.

Compared to a structure based on four or eight sub-pixels, a period six is a preferred sub-pixel layout. Firstly, since this system has a high

transmission, 1/3 of the sub-pixels is used in each view. Secondly, the visibility of the structure is low compared to a structure based on eight sub-pixels, which results in broad black lines between the visible lines.

We have described two dual-view display that use the proposed sub-pixel lay-out. In a first display we use a LCD with a rear barrier or back-light which emits light along light lines. For an off-the-shelf display we obtain small viewing zones. To improve the viewing zones, we can use thinner glass or a dedicated scatterer. In the second display uses the light lines are imaged by means of a lenticular screen into the glass. This embodiment shows good viewing zones.

In this section we describe a dual-view display based on a colored barrier. Firstly, we consider the front barrier construction. In this construction the barrier consists of a periodic structure of red, blue and green color filters with in between the filters possibly a black matrix, see Figure 28. Assuming that the color filters of the LCD run in the vertical direction and consist of red, green and blue filters. In addition we assume that the red, green and blue color filter on the barrier are the same filters as used in the LCD color filter plate and the color filters are orthogonal: a red filter on top of a green filter is always non-transparent, and the same holds for a red filter on a blue filter or a blue filter on a green filter.

The dual-view display works as follows. Let us consider a red pixel, denoted by number 1 in Figure 29. Light from this pixel can only pass through the red columns of the front barrier. The nearest filter is on the right and light passes through this slit to the right and creates the right view. At the same time light from the red sub-pixel on the right of the red slit creates the left view (dashed lines).

It is possible that there are more than one view to the left and right as denoted in Figure 29. Light from, for instance, a red sub-pixel cannot only go through the nearest red slit, but also though other red slits (dotted lines in Figure 29).

By construction, the colored slits have a width that is less than two sub-pixel pitches and, consequently, there is no cross-talk. See Figure 30 in which we assumed that the width of the colored slits is precisely two sub-pixels. Light from the left red sub-pixel goes in a direction orthogonal to the display and not to the left. The same holds for the right red sub-pixel, and so the left and right viewing zones will not overlap. In addition, if there is some black matrix, either in the colored barrier or the LCD, the region between the two viewing zones will be even larger and there is certainly no cross-talk.

To calculate the angles at which the several viewing zones begin and end, we proceed as follows. Let us denote by w the width of a single colored slit, by b the width of the black matrix of the LCD, by p the sub-pixel pitch and by d the thickness of the glass between the LCD sub-pixels and the colored front barrier, see Figure 29. The angle at which the viewing zones start in glass, $\sim\alpha$ and $\sim\beta$ are given by:

$$\sim\alpha = \arctan((6j\, p2p-b/2+w/2)/d)$$

$$\sim\beta = \arctan((6j\, p+b/2-w/2)/d) \qquad (2)$$

where j denotes the number of the colored slit, see Figure 29. The refraction at the glass-air interface, at the viewer side, results in the following angles at which the viewing zones start, α, and end, β:

$$\alpha = \max(-1; \min(1, \arcsin(1.5 \sin(\sim\alpha))))$$

$$\beta = \max(-1; \min(1, \arcsin(1.5 \sin(\sim\beta)))) \qquad (3)$$

where the min and max function occur to avoid complex angles due to total internal refraction and where we assumed an index of refraction of glass of 1.5.

The size of the viewing zones is denoted in Figure 31 as a function of the transmission of the system (colored front barrier and LCD):

$$((p-b)/p)*(w/6p) \qquad (4)$$

where the factor 6 occurs since the transmission of each color filter is approximately 1/3 and for each two sub-pixels there is only one slit.

We observe that for d = 0:7mm, p = 0:1mm, b = 0:025mm there are as a function of w two viewing zones to the left and right if the transmission is less than ≈ 0.18. The first and third zone contain the same information. The same

holds for the second and fourth zone. As discussed above, the viewing zones do not overlap and, so, there is no cross-talk by construction. Unfortunately, the size of the viewing zones itself is too small.

The size of the viewing zones can be increased, by decreasing the size of the glass-thickness d. The angles at which the right viewing zones start and end are presented in Figure 32 as a function of d, where we assumed that $w = 2p$, p = 0.1mm and b = 0.025mm. For d = 1mm there are six viewing zones. For $0.35 < d < 0.7$ there are four viewing zones and for d < 0.35mm there are two viewing zones only. The requirements for an automotive application are satisfied for d < 0.35.

If we increase the resolution, or decrease the pixel size, the same viewing zones can be obtained, if we scale d, b and w by the same factor. So, for sub-pixels of 42µm, the thickness d should be less than $0.042/0.1 * 0.35 \approx 0.150$mm.

In most LCD's made today, the glass substrate has a thickness of 0.7 or 1.1mm. For our construction to work we need relatively thin glass between the LC cells and the color barrier. This can be obtained by a dedicated color filter plate: We start with a normal glass substrate (0.7 or 1.1mm for instance) and on top of that we create our barrier consisting of color filters. Then we place on top of this colored front barrier a thin sheet of glass of for instance approximately 150µm. On top of this glass we put the normal color filter structure. The two layers of color filter should be aligned as shown in Figure 33.

Finally, we present a drawing of a rear barrier consisting of color filters, see Figure 34. This embodiment works along the same lines as the front barrier. Due to the rear barrier, light can only pass in a certain direction through the sub-pixels, as shown in the Figure for two red sub-pixels. The relation between the angles at which the viewing zone starts and ends, α and β respectively, and the thickness of the glass d, width of slits w, sub-pixel size p and black matrix width b is precisely the same as for the front barrier.

In the foregoing we have described a dual-view display that has no cross-talk and large viewing zones. This display consists of a rear or front

barrier of color filters, that run in the vertical direction. For a LCD with normal color filters for red, green and blue light, the barrier consists of successive color filters for red, blue and green light with possibly a blackmask in between.

We have shown that it is possible to create a dual-view display with viewing zones that are 90 degrees large and have no cross-talk. The proposed construction fulfills the needs for an automotive application but is also applicable elsewhere.

The translucent spectra of the color filter should not overlap, otherwise, we obtain cross-talk. For instance, light of the red pixel corresponding to the right view might leaks through the green or blue color filter and is visible in the left view. This is illustrated in Figure 35.

In case the back-light emits light of well determined wave-length (for instance LED light), it is easier to avoid the cross-talk due to the overlapping color filters. The spectra of red, green and blue LED's is well separated. For these light sources it is relatively easy to construct color filters that are translucent for the light of a single LED only.

For the rear barrier the color filters preferably consists of cholesteric color filters. These reflective color filters are more light efficient, since for instance the red filter reflects the blue and green light back into the back-light which makes it possible to re-use this light.

In automotive applications the display is often rotated towards the driver. This implies that the viewing zones should leave the display asymmetrically. In the embodiment presented here, this can be realized by shifting the color barrier. This is illustrated in Figure 36.

Figure 1: An impression of the application of a multi-view display in an auto. In this case the multi-view display is visible by 4 viewers, all perceiving different information.

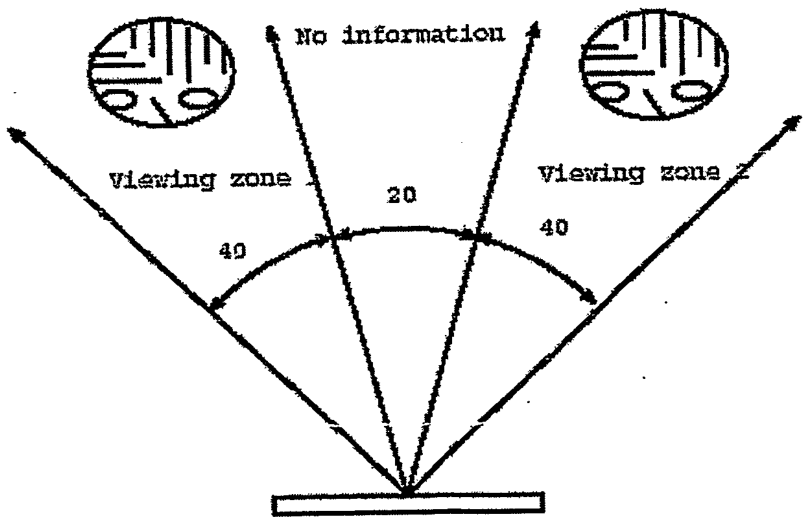

Figure 2: An illustration of the requirements to be fulfilled by an automotive application. The viewing zones for the passenger and driver are approximately 40°, the region in which no information is sent is approximately 20°.

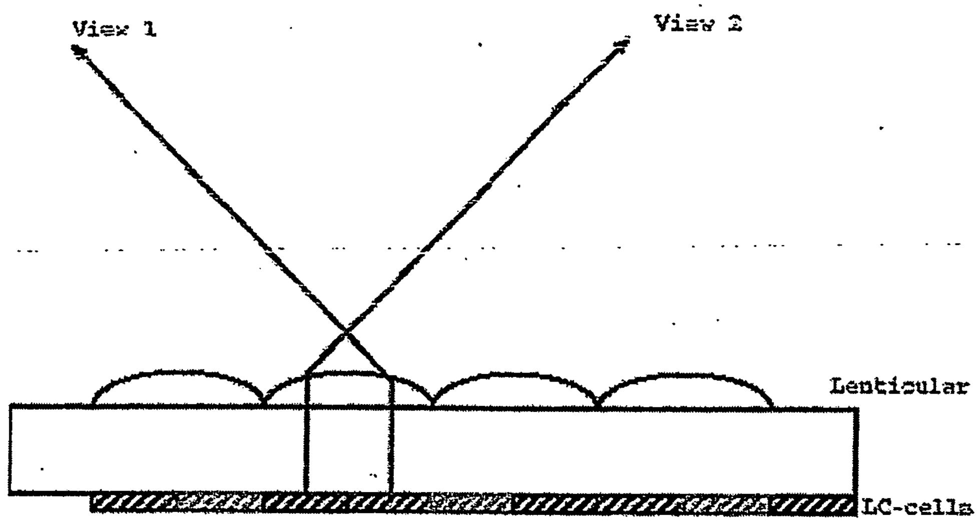

Figure 3: An illustration of a multi-view display based on a lenticular screen placed in front of a LCD display.

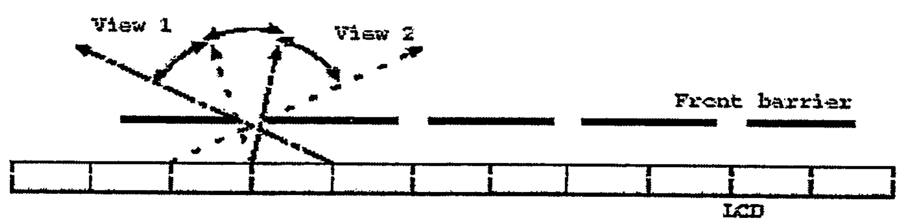

Figure 4: An illustration of a multi-view display based on a front barrier placed in front of a LCD display. There are two views and in between the two views there is a region with cross-talk.

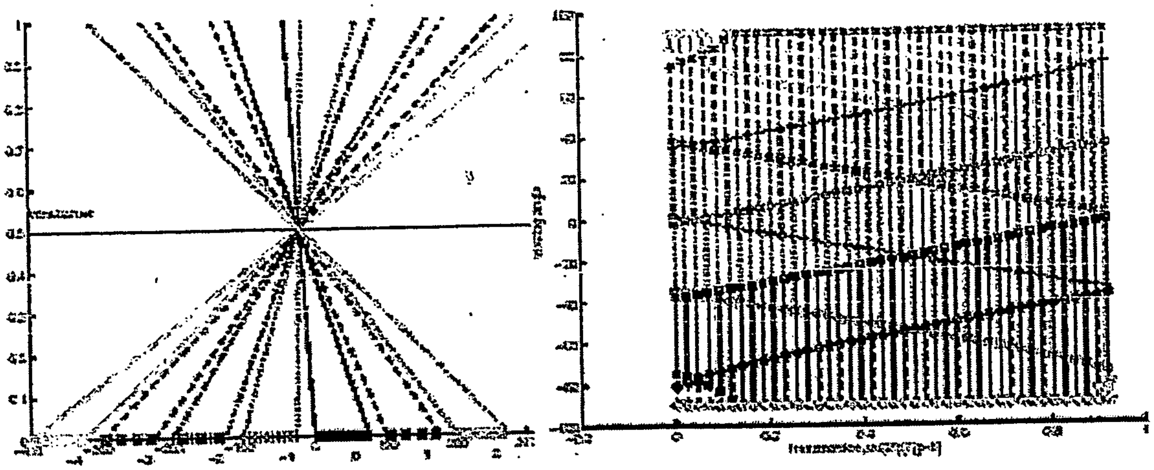

Figure 5: The different views for a front barrier. In the left figure we illustrate the light rays if the width of the slit in the barrier is zero. In this case the views do not overlap due to a blackmatrix of 25μm. As parameters we used: pixel size 300μm, glass thickness 700μm. In the right figure the different views for a front barrier as a function of the width (or transmission) of the slits in the barrier are shown.

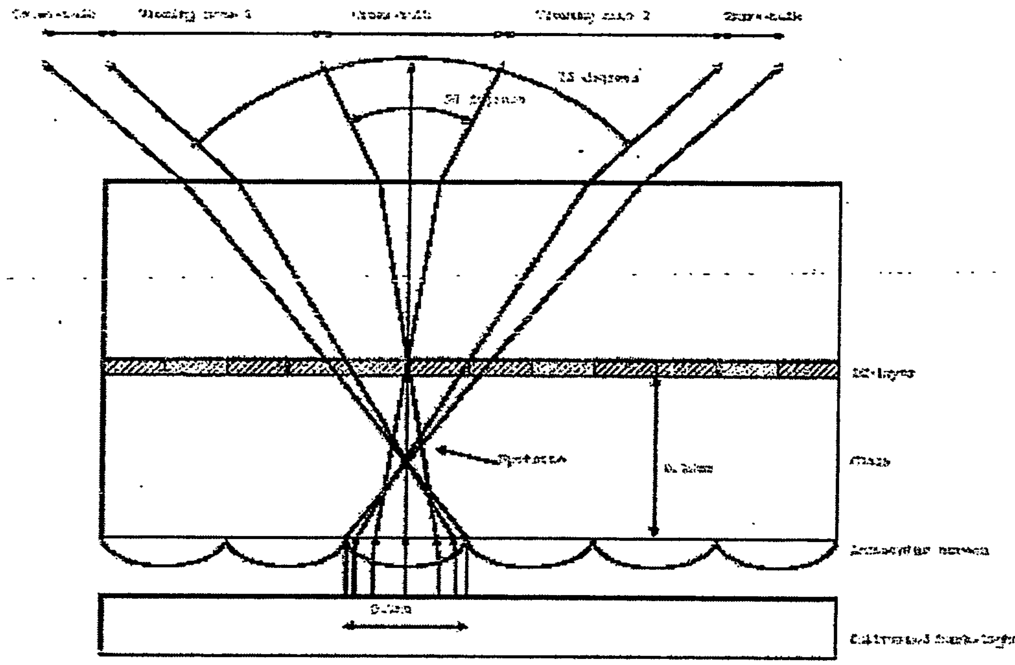

Figure 6: An embodiment based on a lenticular screen between the back-light and the LCD screen. In this embodiment there is cross-talk. Firstly, there is cross-talk in the middle due to the finite spot size. Secondly, there is cross-talk at the edges since light is going through the wrong pixels at the edges (the opening angle of the spot is too large).

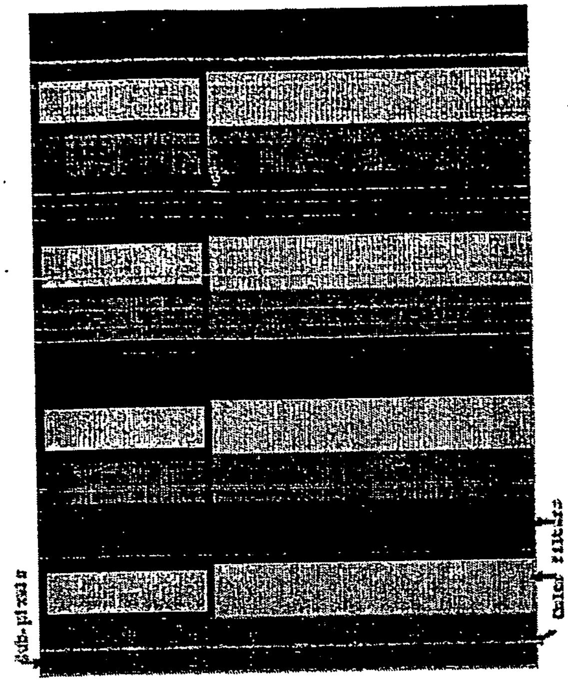

Figure 7: A sketch of the LCD pixel structure. In a normal LCD screen the color lines run vertical. For a multi-view display it is favourable to have the color lines in the horizontal direction as denoted in the figure.

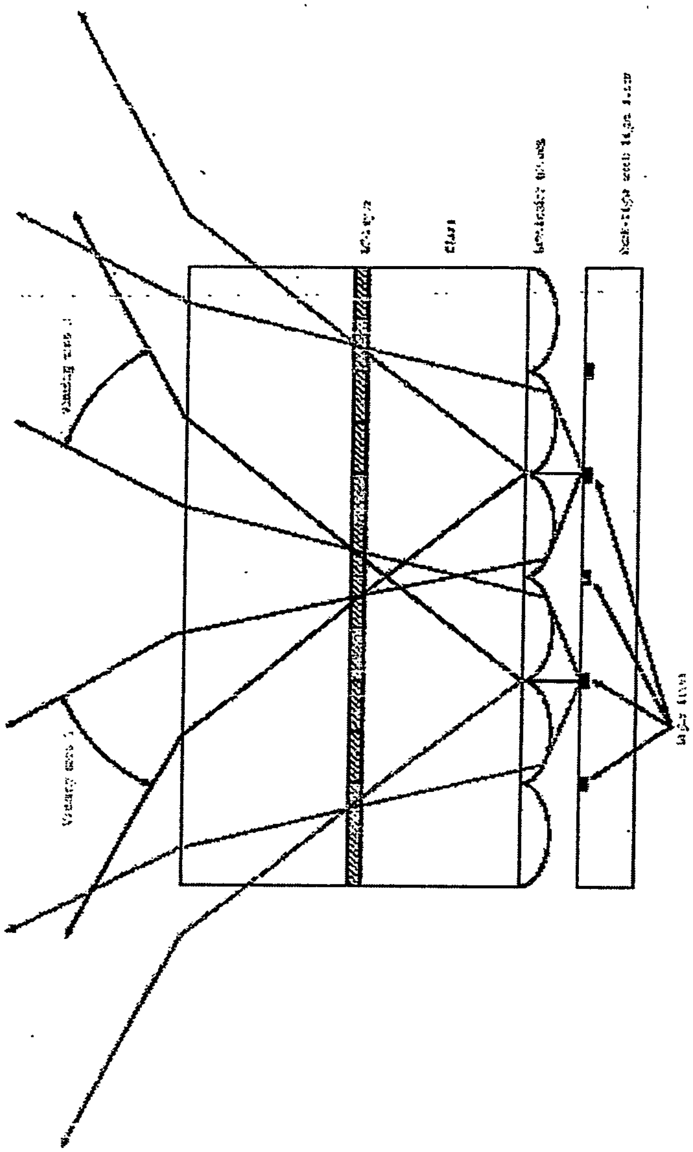

Figure 8: An embodiment based on a lenticular screen between the back-light that emits light along light lines and the LCD screen. In this embodiment the light lines are positioned in between the lenses of the lenticular screen. Not all rays starting at all light lines are drawn for clarity. The pixels that are not used currently will be lit by the other light lines.

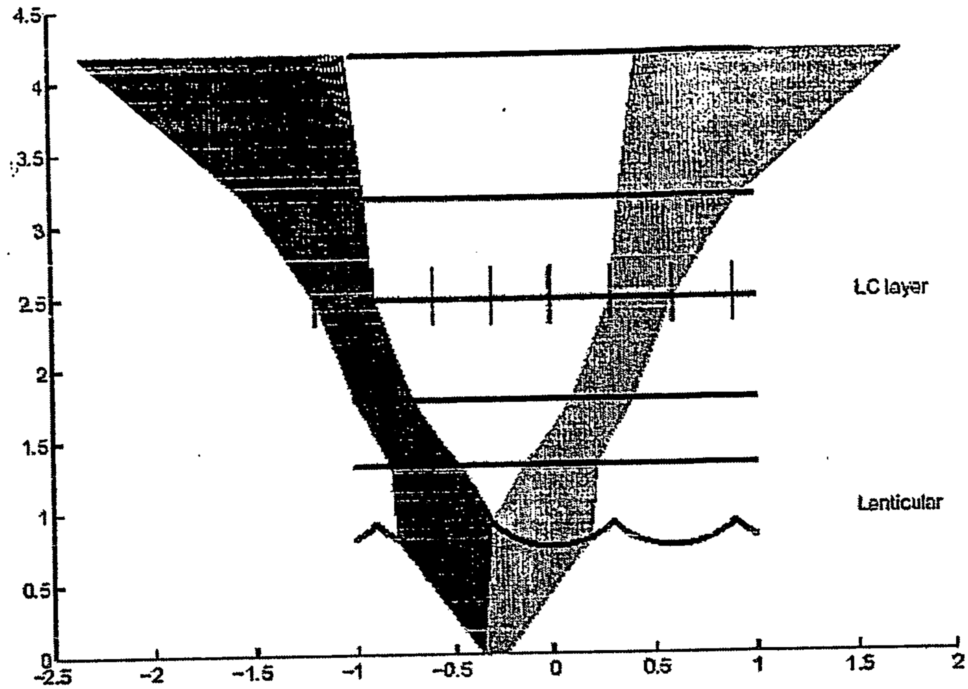

Figure 9: The light rays for our embodiment. In this calculation we used a glass thickness of 0.7mm and a pixel size of 0.3mm. The vertical lines in the LC layer denote the begin and end of a pixel. The size of the light lines is 100μm, the opening angle of the light line is approximately 30°.

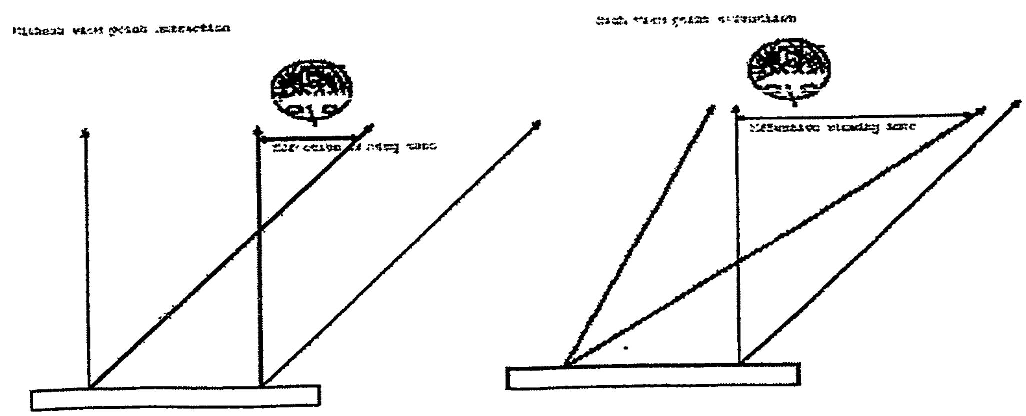

Figure 10: If there is no view point correction the usable viewing zone is less than the viewing zone for each (sub-)pixel.

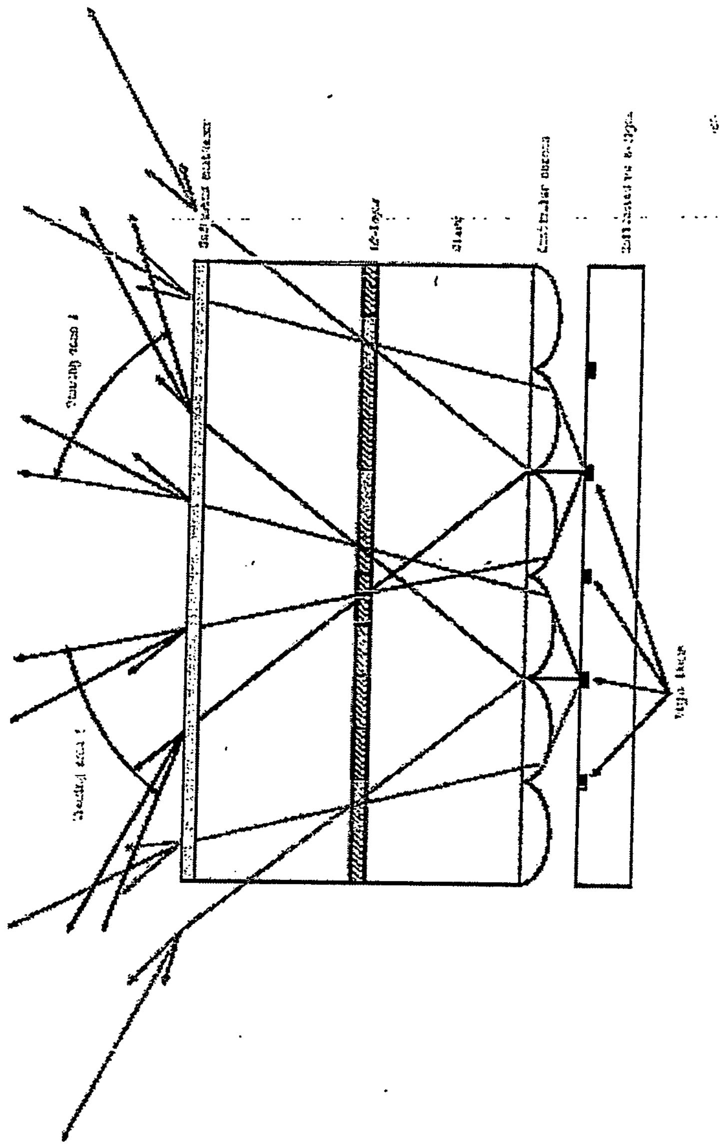

Figure 12: An embodiment as shown in figure 8 with an additional dedicated scatterer on top of the screen. This scatterer results in larger viewing zones.

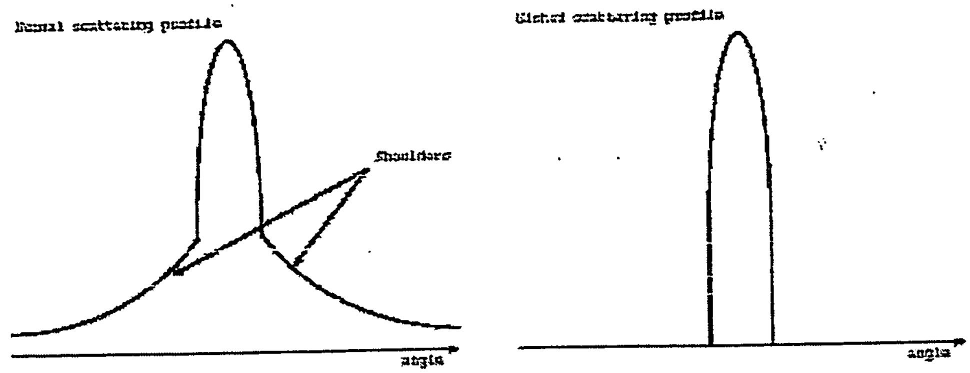

Figure 12: A sketch of a normal scatter profile (e.g. of paper) and the required scatter profile.

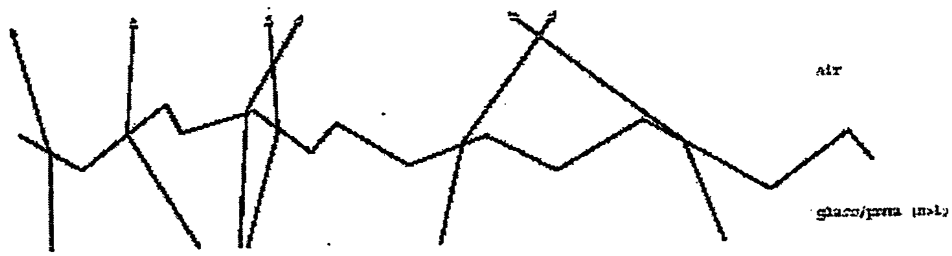

Figure 13: A rough surface with facets that make a controlled angle, will result in a controlled scatterer. In this figure we assumed that the lower part consists of a higher index of refraction material (glass, pmma) and the upper of a lower index of refraction material (air).

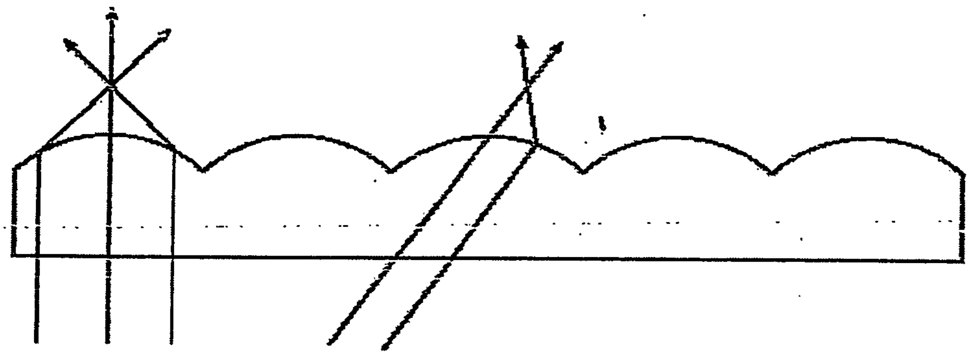

Figure 14: A structured surface. will result in a controlled scatterer. In this figure we assumed that the lower part consists of a higher index of refraction material (glass. pmma) and the upper of a lower index of refraction material (air).

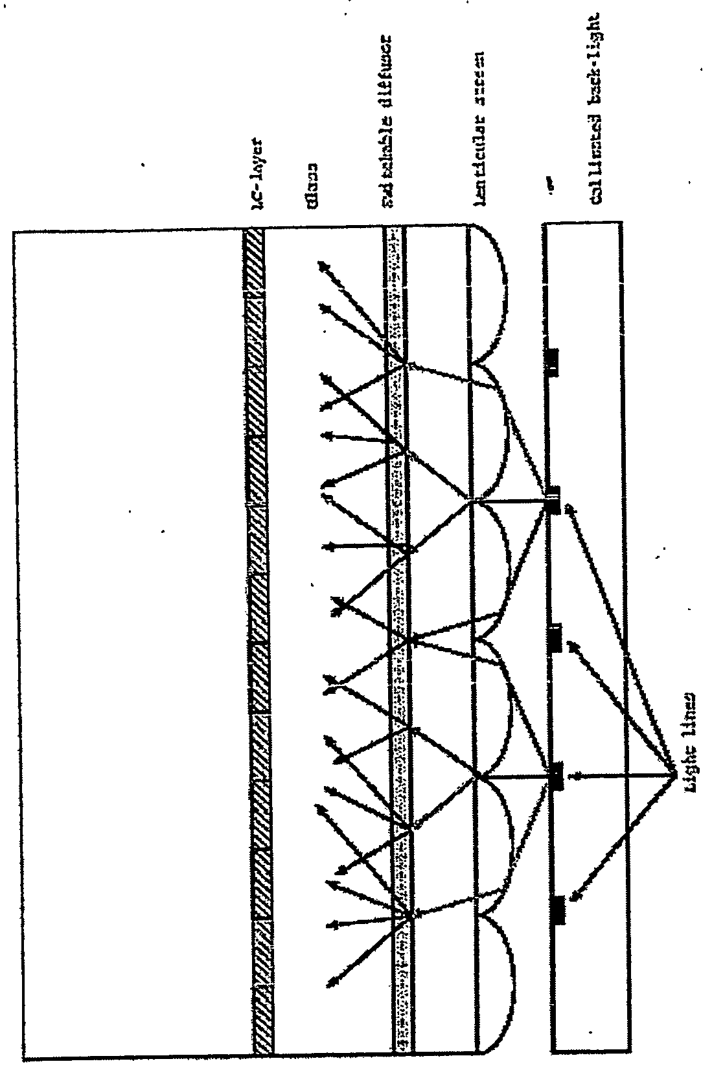

Figure 16: An embodiment as shown in figure 8 with an additional switchable diffuser which is in the scatter mode. In this situation the LCD layer is lit uniformly and both viewers will see all pixels.

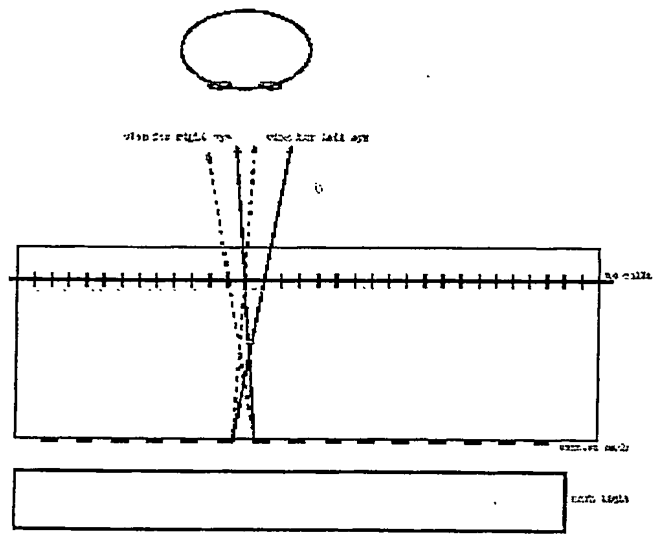

Figure 16: An illustration of a two-views three dimensional display based on a rear barrier. The odd and even column information is aimed at the left and right eye of the viewer.

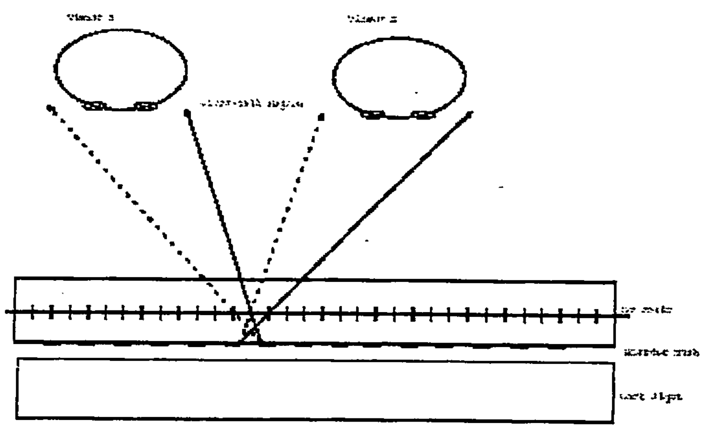

Figure 17: A dual-view display based on a rear barrier suffers from cross-talk: in between the two regions where only the information for the first and second viewer is visible, there is a region in which information for both viewers is visible.

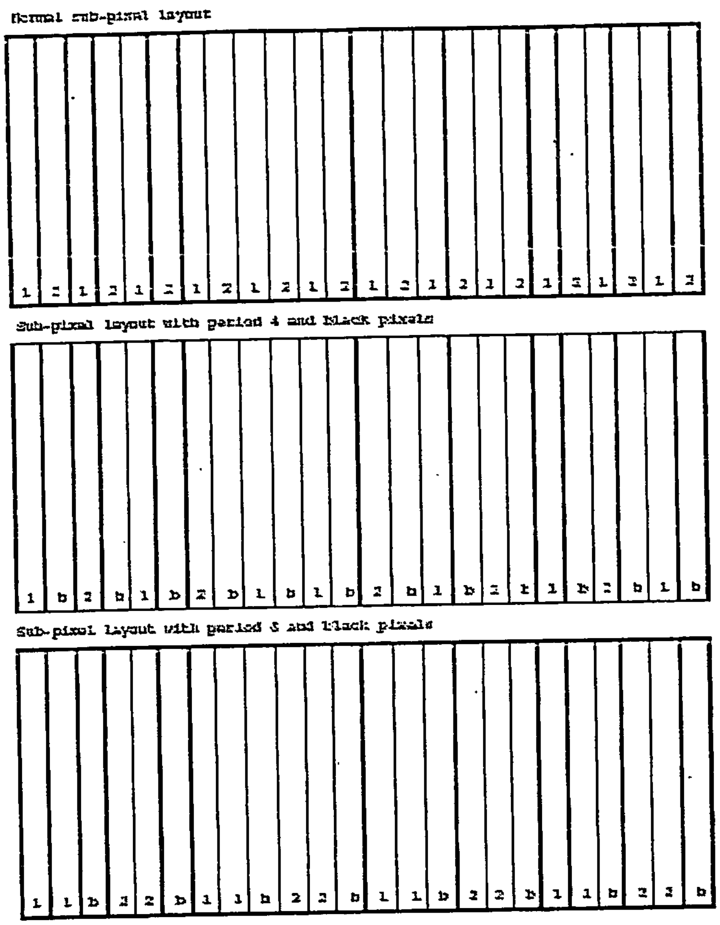

Figure 18: From top to bottom we see three illustration of possible sub-pixel layouts. The vertical sub-pixel lines that are aimed at the first viewer are marked by a 1, those aimed at the second viewer by a 2 and the vertical sub-pixel lines that are left black by a 'b'. On top we see a conventional layout: the odd and even columns of sub-pixels are directed towards the first and second viewer respectively. In the middle picture we see a layout with period 4 with an additional black sub-pixel between the sub-pixels to reduce cross-talk. In the lower picture a sub-pixel layout is shown with period 6 in which two adjacent sub-pixels are directed towards each viewer.

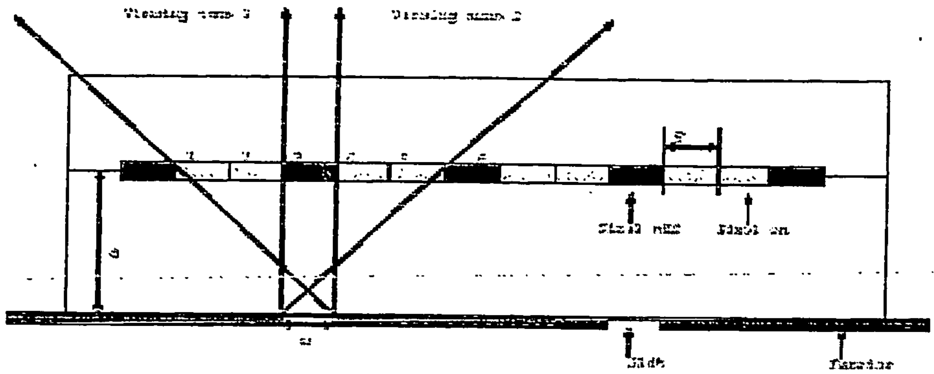

Figure 19: An illustration of the use of 6 sub-pixels to create two views. The second and third sub-pixel are illuminated such that a viewer on the left is able to see them. The fourth and fifth sub-pixel are illuminated such that a viewer on the right sees them. The first and fourth sub-pixel are turned off. The size of the sub-pixel is *p*, the glass-thickness between LCD layer and barrier is *d* and the width of the slit is *w*.

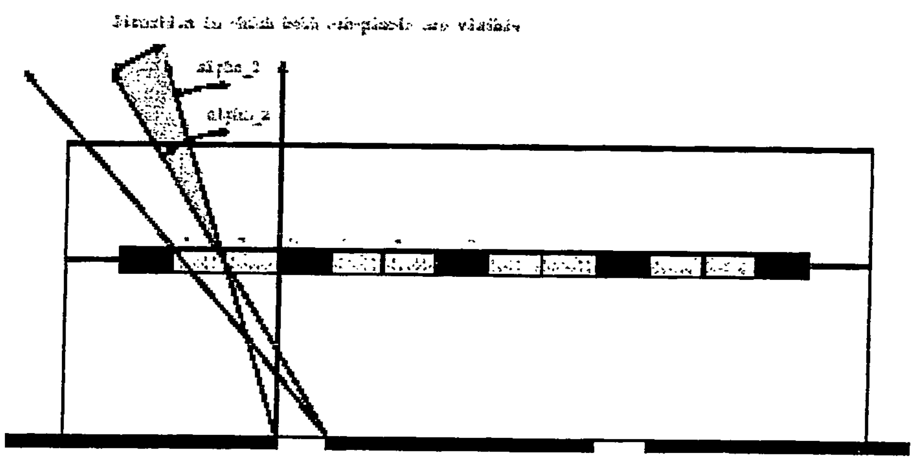

Figure 20: An illustration of part of the viewing zone in which both sub-pixels are visible.

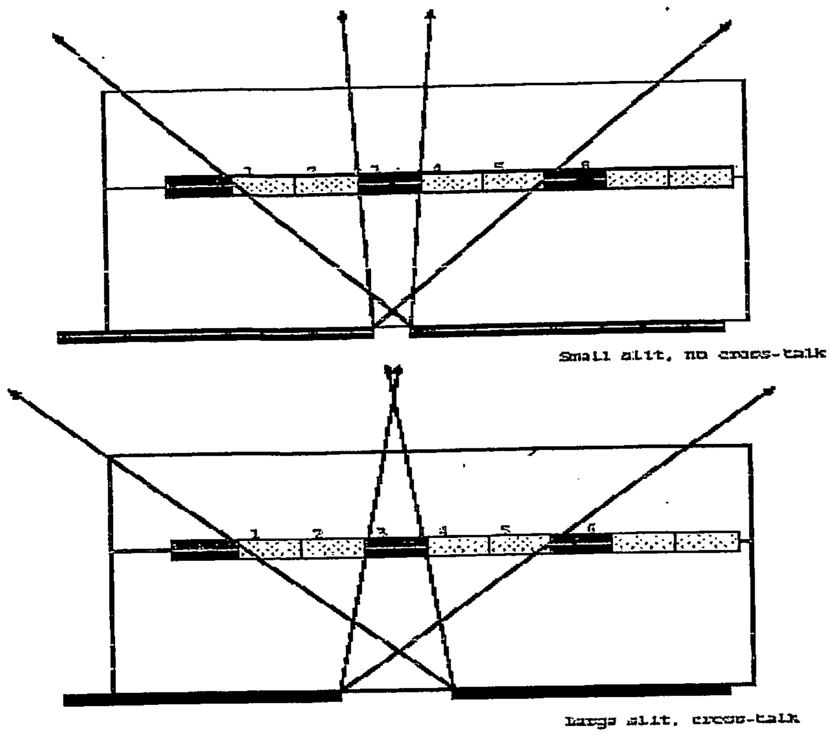

Figure 21: If the slit of the barrier is small, there is no cross-talk. For a large slit we obtain cross-talk in between the two views.

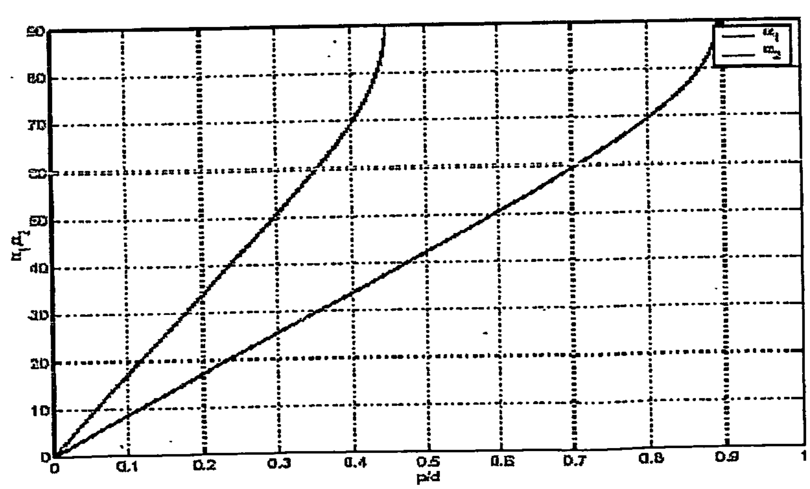

Figure 22: The angles α_1 and α_2 at which the viewing zone begins and ends as a function of $p=d$, where p denotes the sub-pixel size and d the glass thickness if we use a period 6 sub-pixel structure as described in the text.

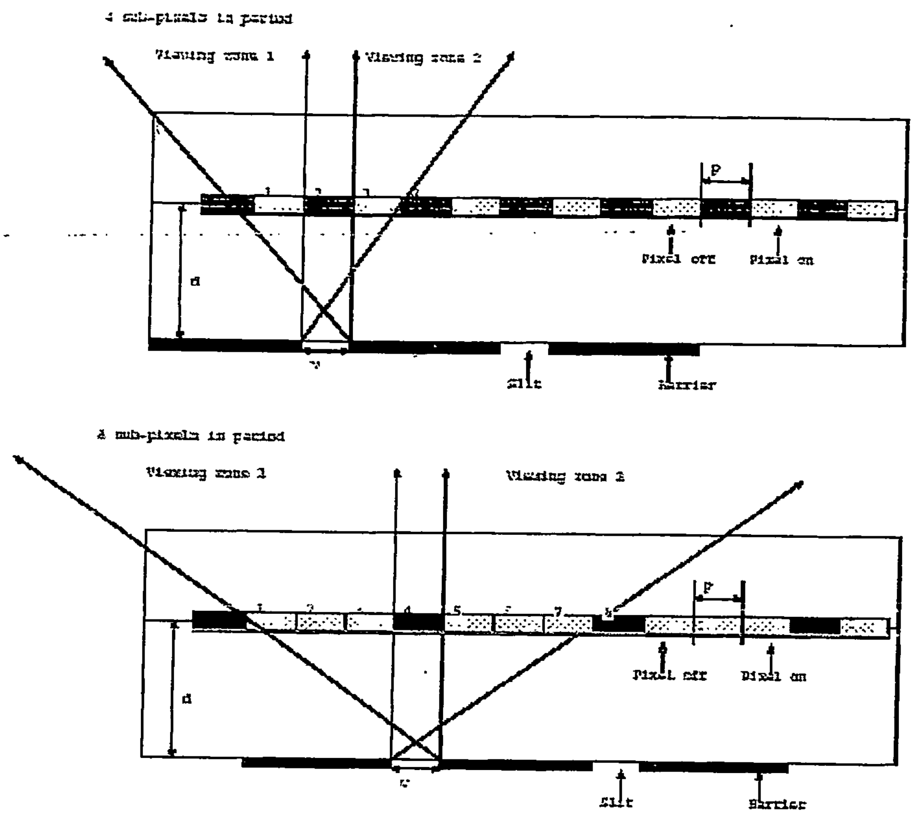

Figure 23: An illustration of an embodiment based on 4 or 8 sub-pixels in every period.

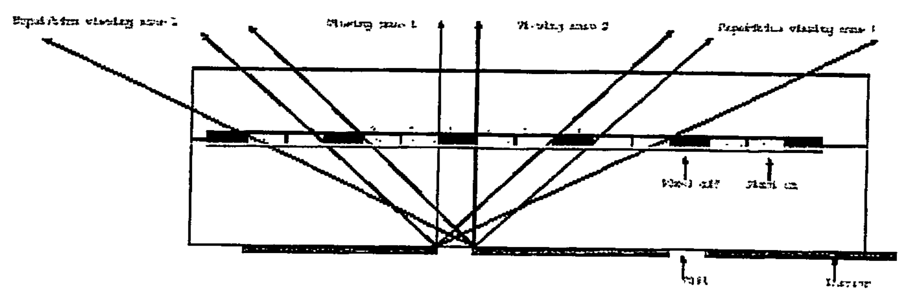

Figure 24: If the opening angle of the light that passes the slit in the mask is too large, we get a repetition of the viewing zones at the left and right.

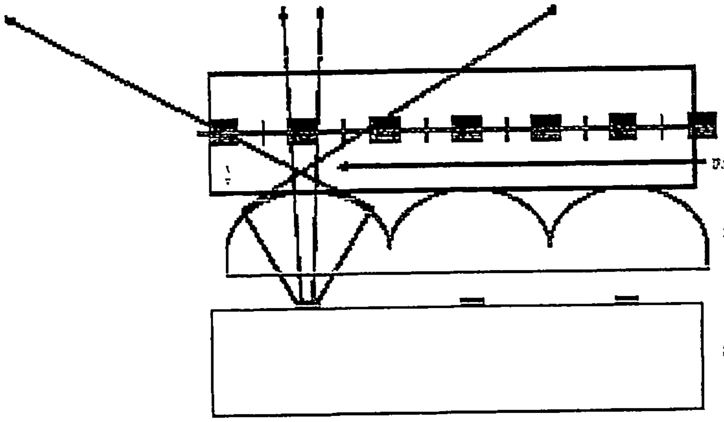

Figure 25: An illustration of an embodiment based on a stack of a back-light that emits light along light lines and a lenticular screen.

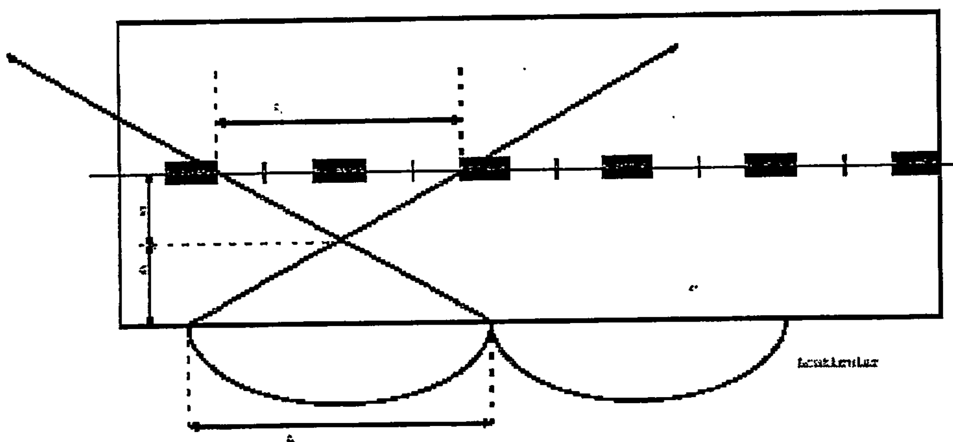

Figure 26: An illustration of closest obtainable position of the light lines in a period 6 sub-pixel structure. The light lines is at 5/11 of the glass thickness from the LC cell.

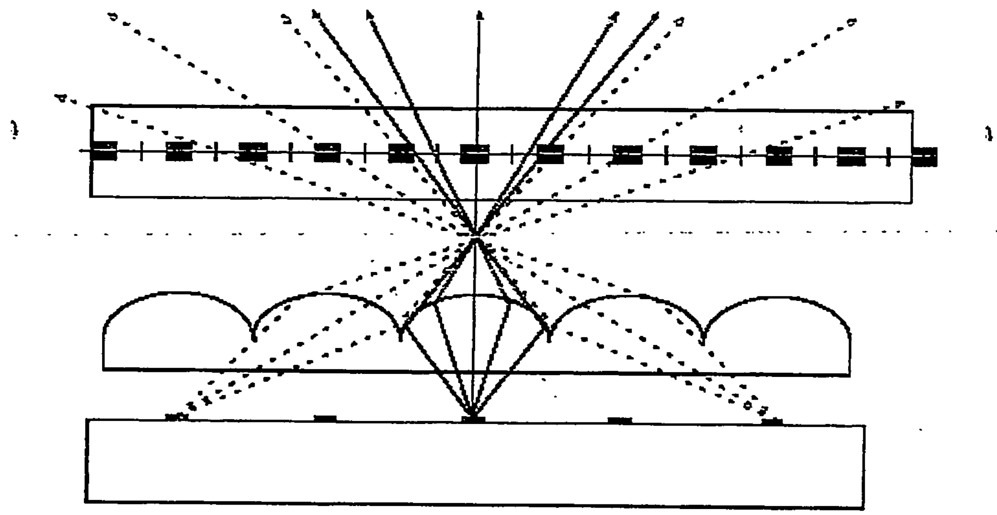

Figure 27: If the magnification factor of the optical system is precisely an integer value, the light rays that pass through neighboring lenses are images on light lines of other lenses. In this Figure only the relevant parts of the light cone coming from some light lines are drawn. In this way the angular spread of the light lines is allowed to be larger than one lens.

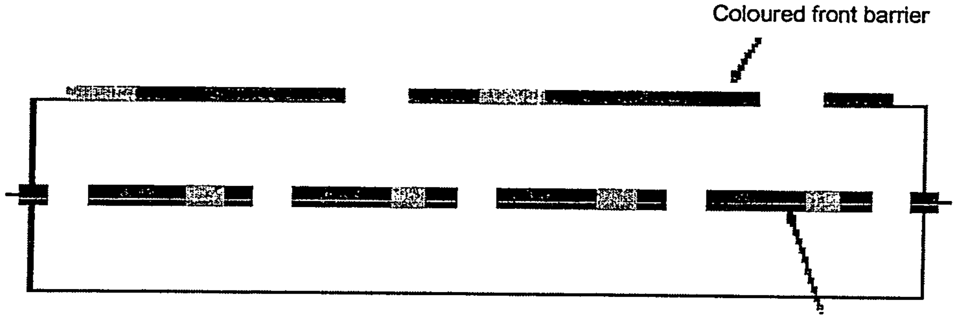

Figure 28: An illustration of (a cross-section) of the LCD and on top of the LCD the colored front barrier that consists of vertical stripes of red, blue and green color filters and a blackmatrix in between the filters.

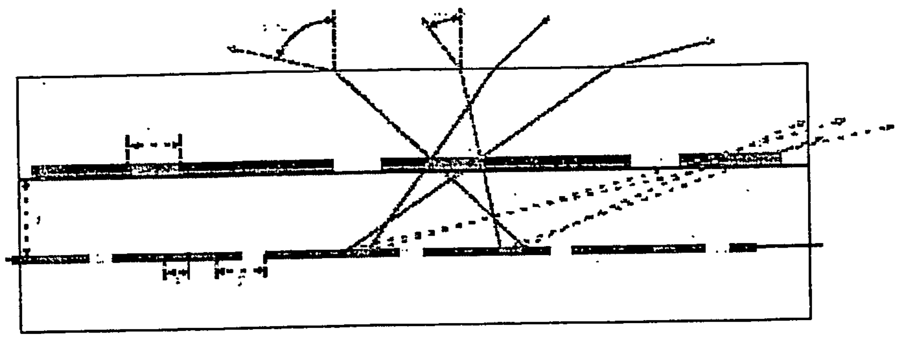

Figure 29: Light from a red pixel passes through the nearest slit to create a useful view. However, there also passes light through other slits, resulting in side-views. For one slit on the right this is denoted for two sub-pixels by the dotted lines.

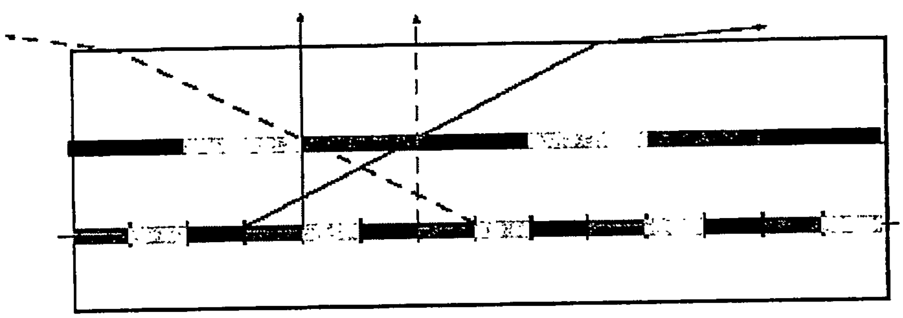

Figure 30: The colored slits in the front barrier have a width less than two times the sub-pixel pitch. In case the width equals two times the sub-pixel pitch, there is still no cross-talk.

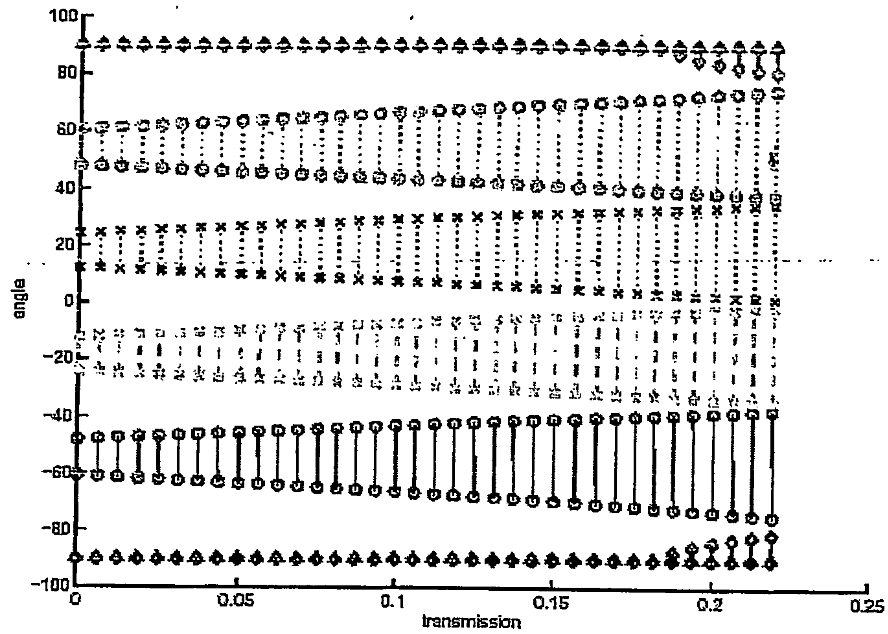

Figure 31: The angle at which the first viewing zone begin and ends as a function of the transmission for p = 0.1mm and b = 0.025mm and d = 0.7mm.

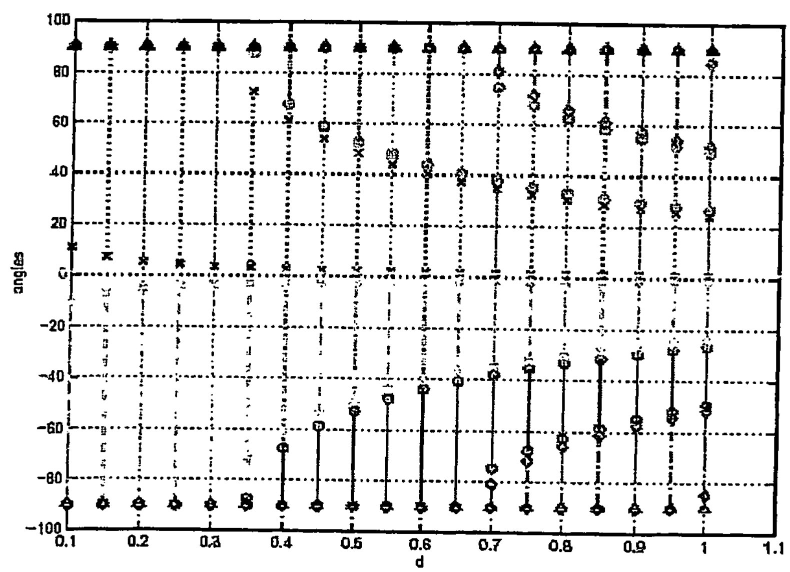

Figure 32: The angle at which the viewing zones begin and ends as a function of d for w = 2p, p = 0.1mm and b = 0.025mm. For d = 0.4 there is only one viewing zone and the requirements for an automotive application are met.

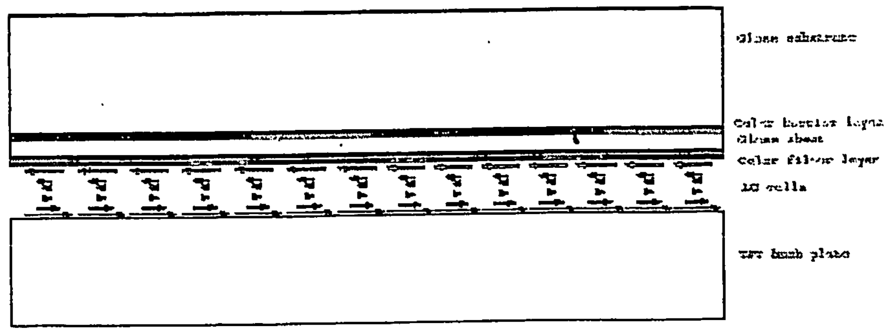

Figure 33: For a small distance between the LC cells and the color barrier the construction might consists of a filter plate that consists of a stack of two glass plates. In this Figure the size of the LC cells is exaggerated.

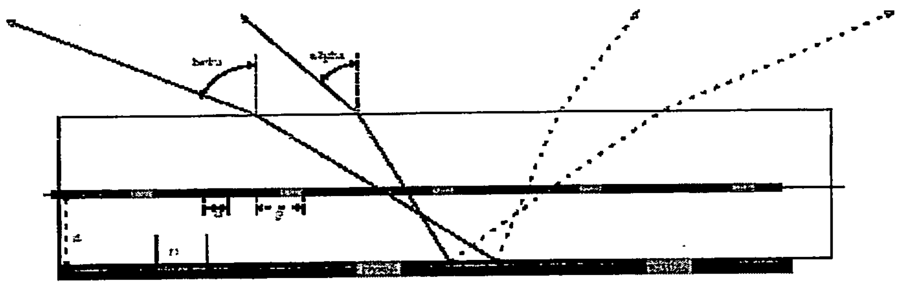

Figure 34: An embodiment consisting of a rear barrier.

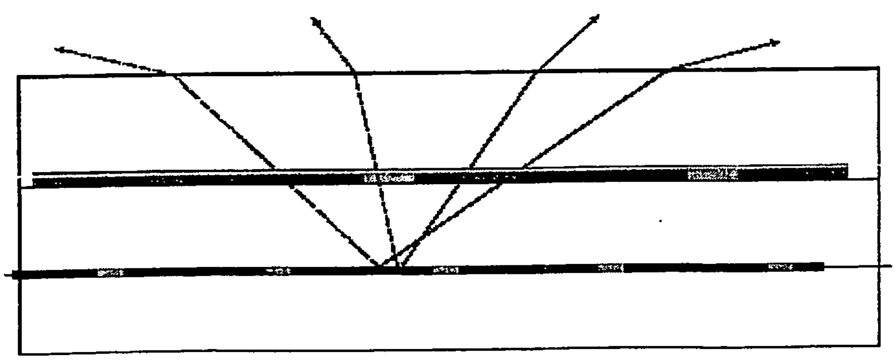

Figure 35: The red pixel contains information for the right viewing zone. If the green and blue filters do not block all the red light, this pixel is also visible at the left side and we suffer from cross-talk.

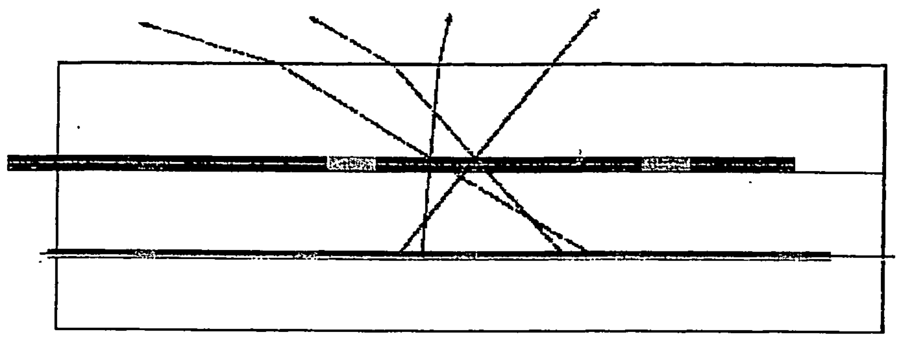

Figure 36: Compared to Figure 29 the color barrier is shifted to the left. The left viewing zones is more aimed to the left, while the right viewing zone is more aimed in a direction orthogonal to the display.